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DIGITAL MANUFACTURING OF DENTAL IMPLANTS USING COMPUTER AIDED ENGINEERING AND FUSED DEPOSITION METHOD

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ABSTRACT

Digitizing and computerization plays a major role in the manufacturing of dental implants. However, dental implants are manufactured by conventional methods and due to the advancements in computer aided engineering and software applications are a important part of the upsurge of technical change that has taken digital manufacturing today. Dentists and patients have equally set high requirements on quality, material, precision and cost so providing digital solution to a dental doctors is a real challenge. This paper focusses on unique and fully digital procedure for the design and manufacturing of dental implants (root) by means of Fused Deposition Method (FDM). Autodesk Inventor 3D CAD software is used for product design, rendering and simulation of dental implant. For ease in manufacturing a customized implant design is provided to the dentists.

KEYWORDS: ***Dental Implants***, ***Implant Root***, ***CAD Modelling***, ***Customized Design & Rapid Prototyping***

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Original Article

INTRODUCTION

Implant dentistry is a help for retrieval of missing teeth. It outstands other techniques for retrieval. That is with removable prosthesis and fixed prosthesis. A dental implant or an artificial root is a small titanium screw that replaces the root of a missing tooth. A single tooth or several missing teeth can be replaced by using dental implants. Dental implants are used to support loose, removable dentures or in combination with orthodontic treatment. Implantation is defined as addition of any object or a material, which is alloplastic in nature either in part or totally into the body for therapeutic, experimental diagnostic or prosthetic reason Dental implants are used to replace the extracted tooth due to a tooth decay, failed root canal treatment and cracking. Front teeth or incisors are lost less frequently than molars. Losing an incisor is an aesthetic problem and also reduces the ability to chew. A single missing incisor can be replaced with a dental crown that is built on top of an implant. Other than replacing a single tooth, dental prostheses can be used to replace multiple missing teeth including all upper and lower teeth. When three or more neighboring teeth are missing an implant-supported bridge is used. When all upper or lower teeth need replacing, 6-8 implants are placed into the jawbone. A framework for the prosthesis is built on top of the implants from a material such as titanium. Replacement teeth made from ceramic or other materials are then built on top of the framework. Finally, the bridge is connected to the implants with screws.[1]

Dental implants are also used in dentures to improve the stability of the removable dental prosthesis. If a removable, complete denture is placed in the lower jaw can have poor stability. Removable dentures can be

supported with mini implants which are thinner than traditional implants and cannot withstand intense forces. Mini implants can be used to improve denture stability when the patient has removable complete dentures in both the upeer and lower jaws. To offer support for the lower jaw denture, four mini implants can be placed in the anterior portion of the patient's lower jaw. To improve the denture stability small holes are made in the denture in order to attach it to the implants. Clips are fitted to the denture, and it is then snapped into the attachment or bar. Dental implants are used to correct the improperly positioned teeth (in adults) while considering the occlusal and aesthetic factors and are also used in orthodontict treatments to direct jaw growth (espeically in children and adolescents). Implants play a major role in orthodontic treatments, particularly in adults, when the patient's own teeth don't offer enough support and cannot be moved safely. [2, 3]

The main advantage of dental implants is its convenience. If placed successfully, dental implants look and feel like your own natural teeth. It is also the most easy and best way to replace the missing teeth. Dental implant is one of the most suitable option for adults. In the case of adolescents and children dental implants are not recommended as their jaw may grow and the implant may be left in an unwanted position.

A patient's general health conditions and medications are taken into account when a dental implant treatment is carried out because it includes surgical procedures. Diseases like diabetes, which can weaken body's immune system, can affect the wound healing and in turn can increase the risk of implant complications. General illnesses are usually not an obstacle in receiving dental implant treatment. However, their effect on the treatment outcome has to be assessed. Osteoporosis medication (bisphosphonate) can also create additional problems after oral surgical procedures. For cancer patients under radiotherapy implant ossification is complicated where hyperbaric oxygen therapy is carried out before implant treatment. Smoking is a important risk factor for implant failure. Heavy smoking increases the risk for ossification and connective tissue problems. Cutting down or quitting smoking improves treatment outcome. [4]

The factors which affect the cost of dental implants are: the brand of dental implants, material and manufacturing porcess of the dental crown and the adversity of the treatment and its procedures. A replacement tooth which is placed on the implant is made of two parts known as an abutment and a crown. The abutment which is made of zirconia or titanium or gold alloy, is a connect or attached to the implant with a screw in order to connect the implant to the crown. The important role of abutment is to determine how the gum shapes around the replaced tooth. The abutment also affects the shape of the crown that is attached to it and determines how easily the teeth can be cleaned. Individual abutments are preferred over standard abutments because they provide beautiful and long lasting results. Dental crowns are made of ceramic, zirconium or gold. A dental milling machine manufactures crowns quickly. Molar teeth are replaced using crowns. The cost of a handmade crown depends on the amount of work it requires and approximate cost of the entire treatment is around 20 to 30 thousand per implant. [5,6]

The implant procedure has been divided into three segments such as planning the treatment, placing an implant and making a dental prosthesis. Planning is the first and important part of the treatment. It is intended to review the condition of the teeth and oral diseases such as caries, gingivitis.. A beautiful and functional dental prosthesis, which looks and feels natural, is the starting point for treatment planning. For a successful treatment the implants has to be placed at the right spot and in the correct position. The dentist takes X-rays and makes plaster models of the patient's teeth. From the X-ray we can find out the structure of the jawbone and how much bone i available to support an implant. Cone beam computer tomography provides a 3D model of the patient's jaws, which allows for different implant lengths

and sites to be tested. An implant is done by drilling a hole in the jawbone and the implant is screwed into it, and finallythe incision is stitched and closed. Models of implants are created once the implant has become fused with the bone and prosthesis is prepared by considering aesthetic factors. [5,6] There are circumstances, during the dental implants that the implants are not properly inserted due to various problems from the patients' end as well as from the dentists' end. Few problems are listed below: Improper ossification of implants: The implant to not fuse to the bone in the desired way.

- Connective tissue infection: Gum infection around natural teeth known as Peri-mucositis.
- Broken prosthesis: Cracks in dental prosthesis.
- Broken implants: Improper design and insertion of implant in proper position.

Most commonly used metal alloys in implants are titanium, aluminium and vanadium. The composition of the metals is 90% titanium, 6% aluminium and 4% vanadium. The titanium alloy (Ti6Al4V, grade 6) commonly used in implants is four times stronger than pure titanium. Zirconia implants integrates well with the bone & gum and also blends well with the colour of natural teeth and is almost corrosion-proof. Polymer and Plastic Composite Implants are still in the experimental stage. [8]

The dental implants are majorly classified into five types: based on Implant Design, attachment mechanism of the implant, macroscopic body design, surface of the implant and type of material. Based on implant design, implants are sub classified as Endosteal (Ramus Frame, Root Form, Blade Form), Subperiosteal, Transosteal and Intramucosal. Based on attachment mechanism of the implant, implants are sub classified as Osseointegration and Fibro Integratrion (Peridontal fibers). Based on macroscopic body design, implants are sub classified as cylinder, thread, plateau, perforated, solid and hollow or vented. Based on surface of the implant, it is sub categorised into smooth, machined, textured and coated. Based on the implant material, implants are sub divided into metallic, ceramic &ceramic coated, polymer and carbon compound. [9]

Modern manufacturing processes related to larger items have become substantially computer controlled, manufacturing of smaller items remain insufficient due to the expense and difficulty in acquiring digital information on small objects.. Computer aided design (CAD), computer aided manufacturing (CAM), rapid prototyping, computer number controlled (CNC) milling and electrical discharge machining (EDM) to fabricate the desired implant product. A technique called computer tomography is used to create an image of the missing tooth for replacement by dental implant. Using CAD tool, the scanned image of patient's teeth is converted to three-dimensional data. This data is stored, duplicated and transmitted electronically for patient's record. Later the CAD model is converted to Stereo lithography (STL) file for the product to be manufactured using additive manufacturing methods such as selective laser sintering, laminated object manufacturing, fused deposition modelling and three dimensional printing. [10].

LITERATURE REVIEW

P. J. Kaleemphasised on Rapid Prototyping (RP) technology (Additive Manufacturing), which helps in medical field to manufacture the human body implants which is impossible to be manufactured by any means of conventional mechanical manufacturing processes. This technology, nowadays, is used to manufacture mandible implants made from titanium. This 3D printed model helps doctors in dental surgery, dental implant fixation and in exact positioning [11]. As discussed by Dmitri Brodkin (1999) on Solid free form fabrication techniques like fused deposition modelling and

three-dimensional printing are used to create a dental restoration. Three-dimensional printing comprises of ink-jet printing which gather information from CAD file and implant is fabricated by depositing layers of powder [12]. Ravikumar Ramakrishnaiah (2016) targetted on the design of customized dental implant root using softwares like Geomagic and Magics. ARCAM A2 electron beam additive manufacturing technique is used to fabricate the implant design [13].. With the help of Autodesk Inventor solid modeler Mohammad T. Hayasi (2009) illustrates, the basis of machine path generating system is direct slicing from design-by-feature [14]. Jae-Hoon Lee (2005) defined the design aspect of an implant root where implant diameter is the dimension measured from the peak of the widest thread to the same point on the opposite side of the implant. It is studied to be more significant than the implant length in the allocation of loads to the surrounding bone. Atleast 3.25 mm in diameter is needed to ensure satisfactory implant strength and most implants are approximately 4 mm in diameter[15].

METHODOLOGY

Figure 1 represents the methodology adopted for dental implant design and digital manufacturing. Due to high global competition and rapidly changing technology, product life cycle has become shortened, customers require customization of product services, and markets have become highly diversified and globalized, the Design and Manufacturing (D & M) industry faces many challenges. The total process of dental implants manufacturing takes a minimum of 3 to 4 weeks to deliver to patient. Autodesk inventor is used to model the root of dental implant and as per the patient's dental implant root requirement unity software does the customization of the model. Finally the STL file produced is assigned to the rapid prototyping machine for manufacturing the product which uses cura software for slicing the model layer by layer and exported to repetier software for generating G codes for manufacturing the product.

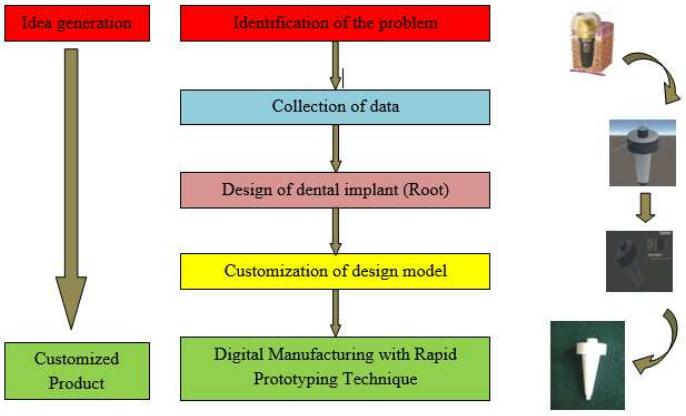


Figure 1: Flowchart of Dental Implant Design and Digital Manufacturing

DESIGN OF A DENTAL IMPLANT

Implant abutment and implant fixture (artificial tooth root) are the components of dental implants. Presently, the focus is on designing of artificial tooth root. The fixture is that part of the implant that's implanted in and becomes fused with the jawbone It's the portion that lies below the gum line and, for all useful purposes, can be considered to be an artificial tooth root. Diameter and length of an implant fixture are the parameters considered for designing of the root. As seen in Figure 2, the basic 3d model of an implant root with 3mm diameter, 10mm length is created using Autodesk Inventor. The diameter varies from 3mm to 7mm while designing an implant fixture. The increase in diameter results in a

higher percentage of bone contact by increasing the surface area of the implant which gives more initial stability and resistance to stresses.. Similarly, length of an implant fixture varies from 8mm to 13mm. The design prefers the use of shorter length fixtures to clear out occlusal forces over large implant surface area to avoid unbearable stresses at the interface. But increase in implant length may only increase the success rate to certain extent.

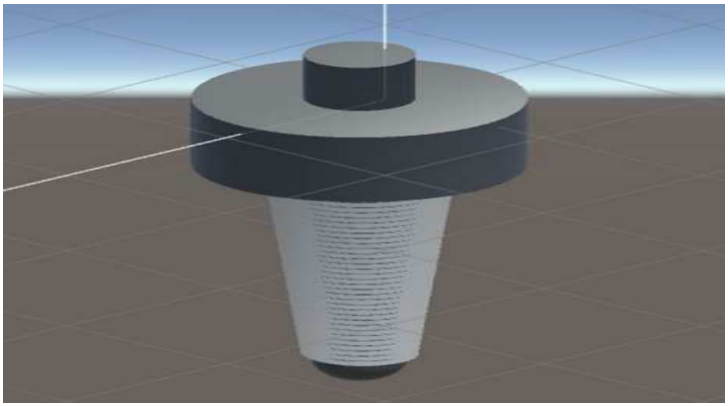


Figure 2: Design of a Dental Implant Root using Autodesk Inventor Software

CUSTOM-MADE DESIGN OF AN IMPLANT

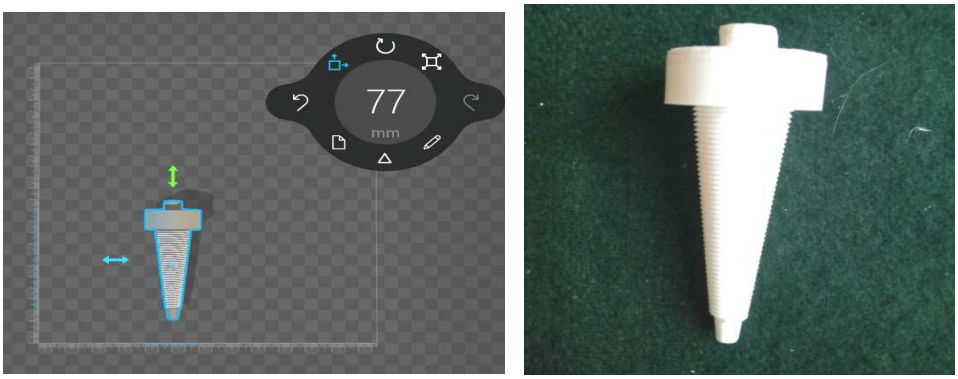
Commercially available dental implants may not be suitable to the patient's requirement in terms of sizes in length and width, hence there is a need for custom-made implants that suite the clinical conditions and patient requirements. Figure 3a is standard CAD model of an implant and Figure 3b is customized CAD model of an implant as per the patient requirement. Therefore the main objective of this research paper is to design and fabricate customized root form dental implant clinically based on patients' requirement in a much less time and the implant can be fabricated by a surgeon clinically using software application. The custom-made design of an implant is created using unity 3d which further incorporates with the software application to manufacture the implant clinically, in turn clinically implant model is fabricated using rapid prototyping technology.

(a) **(b)**

Figure 3: (a) CAD Model for Standard Implant Root (b) CAD Model of a Customized Implant Root

MANUFACTURING OF A DENTAL IMPLANT

After designing the CAD model of an implant, next process is using Cura open source software, to slice the STL model into layers and then using repetier software generating G codes to control the movement of the extruder nozzle in various axis of a rapid prototyping machine. Figure 4a shows the axis direction as an initial setting for manufacturing of the product. Figure 4b shows the manufactured product using rapid prototyping machine.



(a) **(b)**

Figure 4: (a) Axis Reference to Build the Product
(b) Rapid Prototyping Manufactured Product

RESULTS AND DISCUSSIONS

In earlier days implants were manufactured by machining process known as machined or turned implants. The machined implant requires longer healing time(3 to 6 months) before loading crown to the patient due to machining defects such as surface deformity leading to bone-forming cells which leads to accumalation along the surface grooves. In order to overcome the surface treatment, process like titanium etching is done to enhance the viability and cellular adherence. Later, additive manufacturing methods such as selective laser sintering, laminated object manufacturing, fused deposition modelling and three dimensional printing were used to manufacture the standard implants. But these implants may not suit all the patients' requirements because of varied jaw size of different patients, hence this demands for custom-made, clinically manufactured dental implant to match the clinical conditions and patient requirements in turn to obtain an advantage of reduced manufacturing lead time, cost treatment lead time, and accuracy.

Using digital manufactuing technique, manufacturing of dental implant roots are custom-made as per the requirement of the patient and also drastically reduces the manufacturing lead time, cost and helps the surgeon to manufacture implant root clinically.

CONCLUSIONS

From this study we come to understand the effective and unique method to manufacture customized dental implant digital design for complex dental root diseases/problems. The geometry of root is created using software based on the calculated position of the damaged area or tooth lost according to the patients' requirement. The implant (root) is customized by changing the features such as number of threads, pitch of the thread, length and diameter of the implant based on the geometry created. The dental implant is manufactured with good mechanical and geometrical properties using Computer Aided Engineering and Fused Deposition Method which replaces the conventional manufacturing.

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